Jet Propulsion Laboratory
California Institute of Technology

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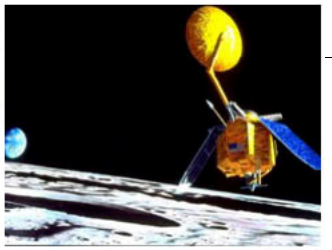
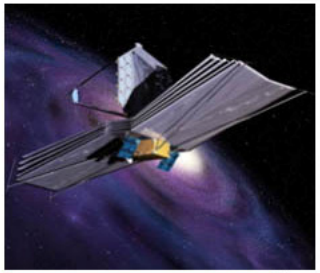
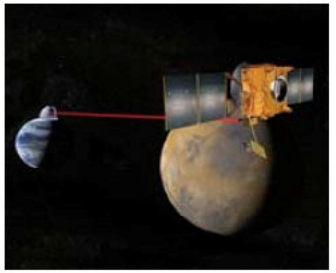
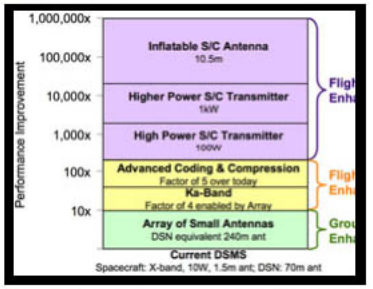
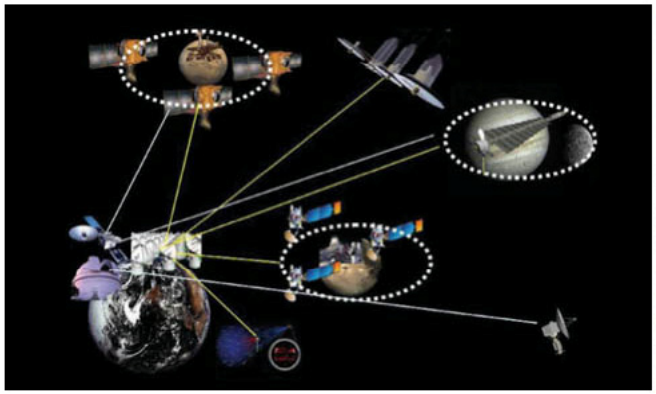






Uplink Coding

Fabrizio Pollara, Jon Hamkins, Sam Dolinar,
Ken Andrews, Dariush Divsalar
Communications Architectures & Research Section



Uplink Coding
Purpose and Goals of Briefing[1]

- Show a plan for using uplink coding and describe benefits
- Define possible solutions and their applicability to different types of uplink, including emergency uplink
- Concur with our conclusions so we can embark on a plan to use proposed uplink system
- Identify the need for the development of appropriate technology and infusion in the DSN
- Gain advocacy to implement uplink coding in flight projects

[1] ***Action Item EMB04-1-14*** **– Show a plan for using uplink coding, including showing where it is useful or not (include discussion of emergency uplink coding).**

Uplink Coding
Outline

- Four categories of uplink
- Current uplink coding system
- Benefits and limitations of coding for uplink
- Preliminary recommendation for each category of uplink
- Other strategies to improve uplink
- Summary

Uplink Coding
Introduction

- **Different uplink applications have different requirements. They may require different coding solutions**
- **We have categorized uplink coding into four application profiles:**
  - **Type A - Emergency uplink: 8 bps; ~100 bits long messages, very bursty usage**
  - **Type B - Routine command and ARQ (Automatic Repeat Query) acknowledgments: 1 to 4 Kbps; several ~100 bits long messages**
  - **Type C - File uploading: 4 to 1000 Kbps (e.g., full reprogramming of Electra radio requires 1 to 2 Mbytes)**
  - **Type D - Human missions: 20 Mbps**

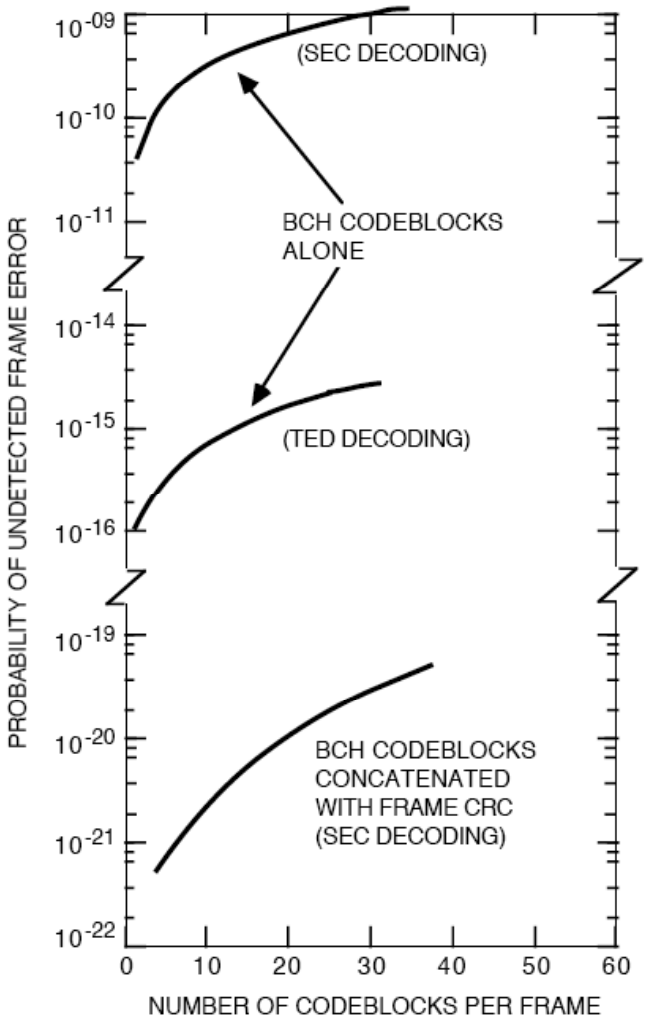
- **Characteristics of uplink coding:**
  - **It must provide extremely low undetected error rates (except Type D)**
  - **Flight implementation complexity must be low**
  - **Requires fast acquisition (short blocks). Except for Type C and D**

Uplink Coding
Current uplink coding system

- (64,56) BCH code
  - Hard decision decoding (2 dB loss wrt. to codes admitting soft decoding)
  - SEC (Single Error Correction) or TED (Triple Error Detection) mode
    - 1.1 dB coding gain in SEC mode
    - No coding gain in TED mode — 0.6 dB loss
  - Very low undetected frame error rate (See figure). Missions requirements vary depending on phase of mission and criticality of data
- The current coding system is simple and reliable, but fails to provide any appreciable coding gain. It is operationally inefficient and obsolete

Notes:
- There is a plan to add a (7,1/2) decoder on FPGA to future SDST; General Dynamics has an implementation for it (B. Cook, B. Shah, G. Glass)
- Currently the SDST receiver output is hard quantized symbols only (2 dB loss)
- SDST receiver must operate at lower E_s/N_o (with new coding)

Undetected Error Performance
(Input BER = 10^{-5})



[From CCSDS Green Book]

Uplink Coding

Performance benefits of uplink coding

- Improved uplink coding provides "coding gain" (reducing the required EIRP), while preserving the required very low undetected error rate
  - The effective improvement depends on the modulation index. To realize most of the available coding gain the carrier power threshold must be reduced (Important for for Type A uplink)
  - Coding gain comes at the expense of a decoder on the S/C. Single FPGA decoder for Types A,B,C is feasible

Type A

- Approach: Improve channel performance by using inner code — keep current BCH code for error detection (cannot use CRC code – block size too short, too much overhead)
- Available coding gain = ~3.8 dB with (3,1/2) code. Effective gain with improved carrier power threshold = ~ 1.7 dB
- Requires interleaver to break error bursts
- (7,1/2) code not recommended because burst are too long (requires longer interleaver)

Type B

- LDPC (same as for downlink) block size=1024 bits
- Available coding gain = 8.8 dB
- Error detection using CRC code
- Need FPGA LDPC decoder … same as for in-situ link

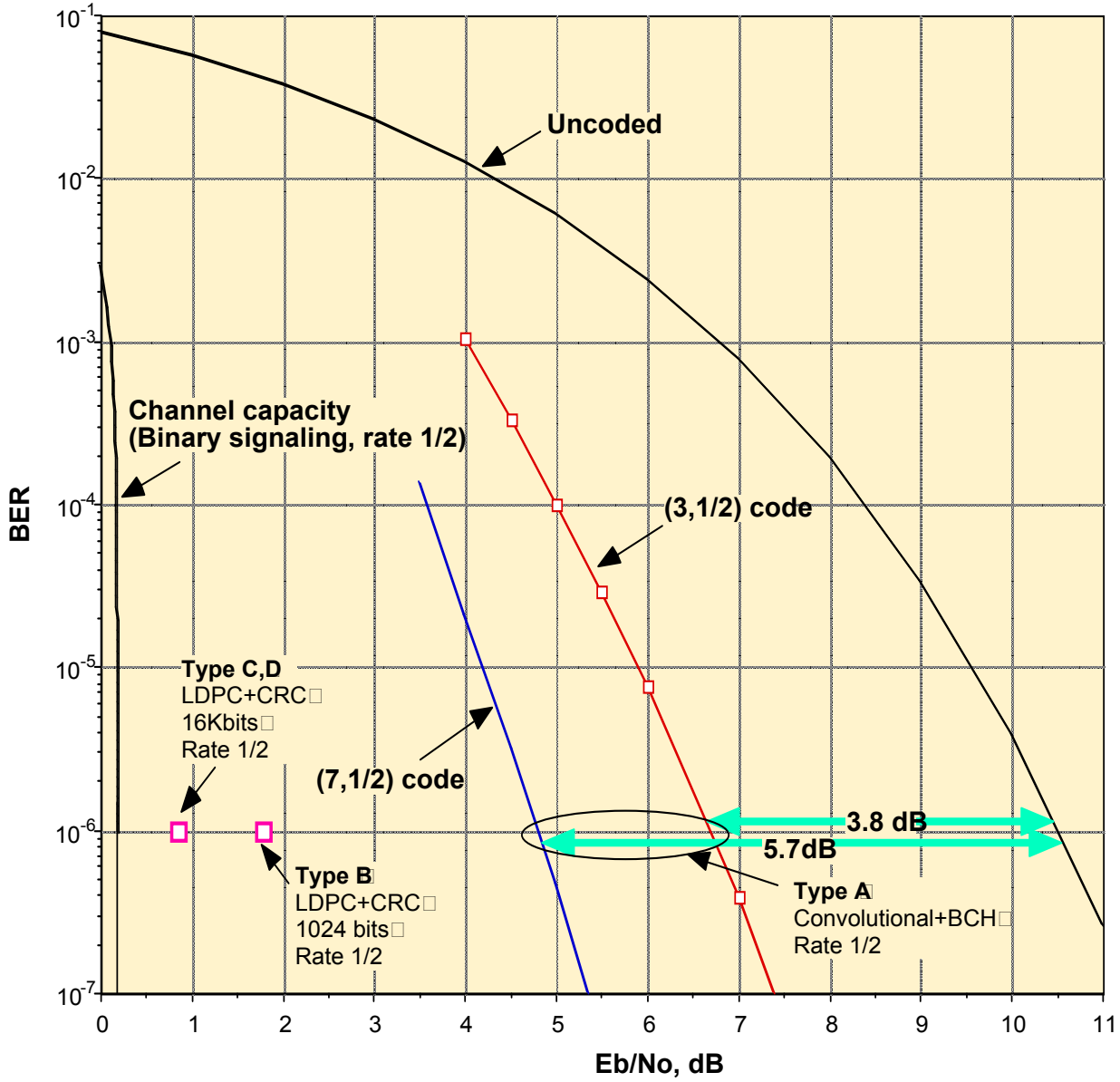
[Final recommendation depends on results of in-depth study]

Type C,D

- LDPC (same as for downlink) block size=16K bits
- Available coding gain = 9.7 dB
- Error detection using CRC code
- Type D needs fast on-board LDPC decoder (20 Mbps !)

Uplink Coding

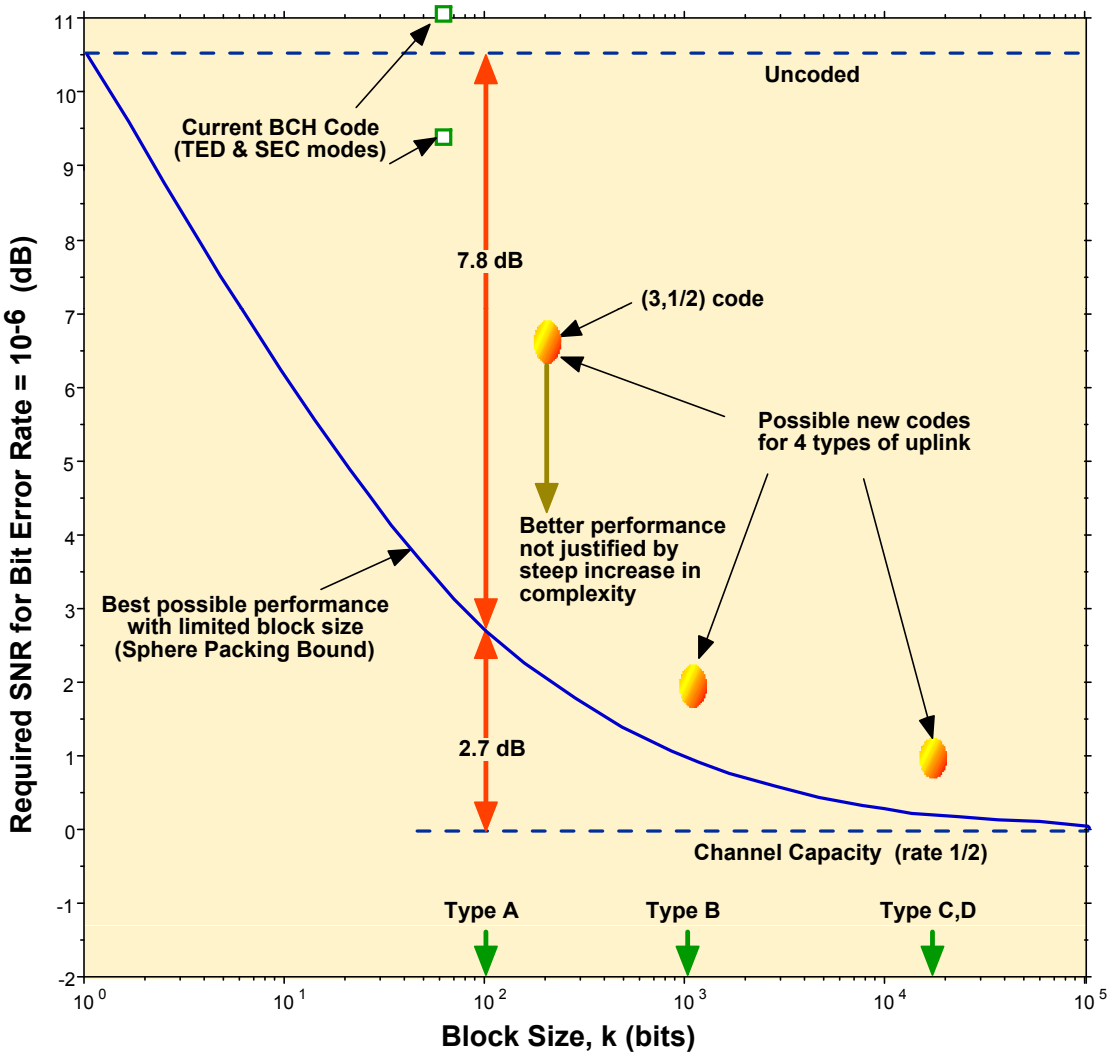
Performance benefits of uplink coding



Uplink Coding

Limitations of uplink coding due to short block size

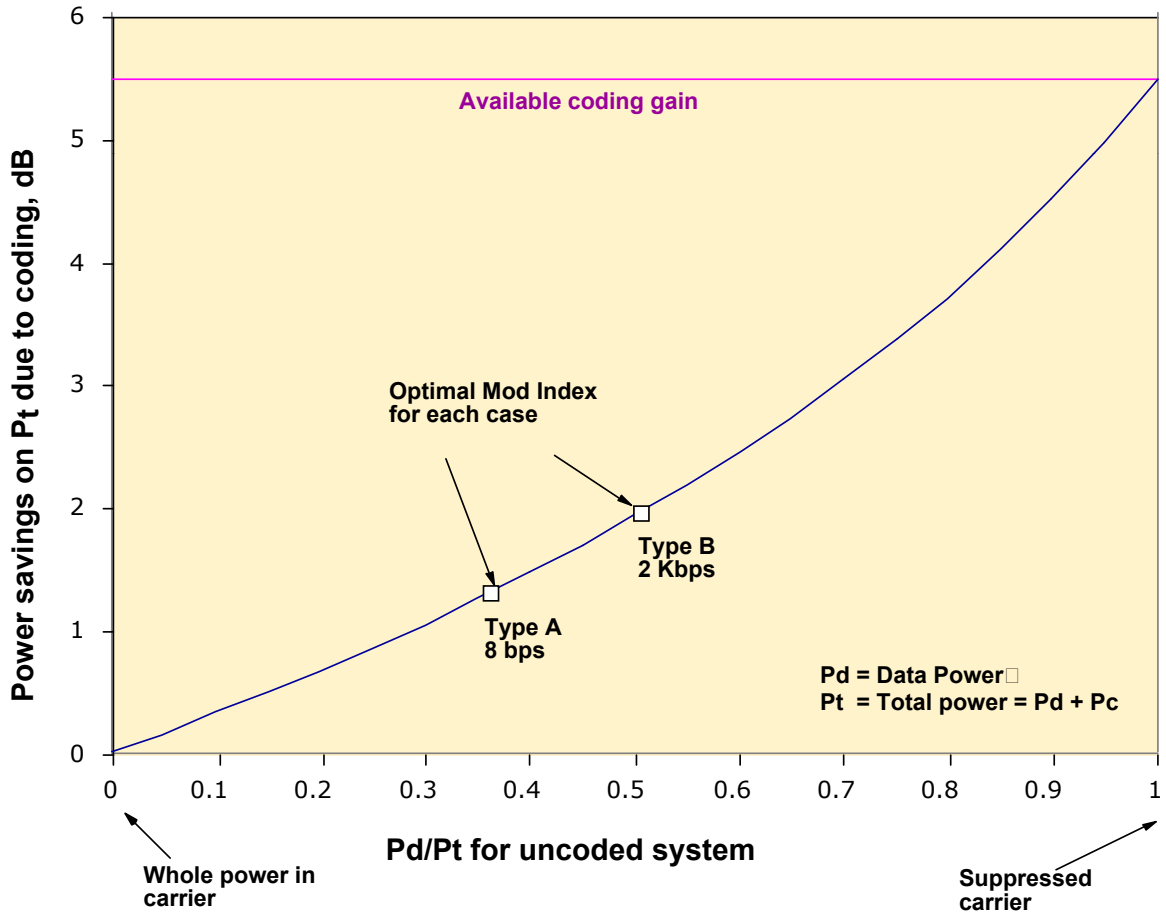
- Coding performance varies significantly with constraints on information block size k
  - k = 1 no coding possible
  - k = ∞ capacity limit is approached
- For uplink, especially emergency, block sizes must be short (~100 bit for emergency) to limit message duration
  - Example of frame duration:
    - 8920 bits at 8 bps = 18 min.
    - 100 bits at 8 bps = 12 sec.
- Recommended block sizes [To be verified during study]:
  - Type A ~100 bits
  - Type B 1024 bits
  - Type C,D 16K bits



Uplink Coding

Limitations of uplink coding: need of high carrier power

Example of reduced benefit of coding due to high carrier threshold – (7,1/2) code



- Current (emergency) uplinks require a large carrier power to simplify initial acquisition
  - The figure shows the effective Pt power savings for different Pd/Pt allocations
- Larger savings can be obtained if the carrier loop bandwidth is reduced and the phase stability is improved
- Smaller loop bandwidths may require more complex acquisition methods, including open loop methods (FFT)
- Non-coherent modulations are also an option

Uplink Coding

Other strategies for improving uplink

- Uplink through relay orbiter (analogous to EDL methods under consideration for MSL). This realizes the sharing of resources of a true network
- Other kinds of modulations (as used for EDL):
  - Coherent FSK (3 dB worse than coherent BPSK, but simpler)
  - Non-coherent FSK (2 dB worse than coherent FSK; no carrier lock required)
- Use suppressed carrier when possible.
- Switch off carrier after prescribed time, when acquisition should have occurred

Uplink Coding Summary

- Classified uplink coding into four representative categories
- Presented preliminary recommendation for uplink coding for each category (Requires detailed study)
- Available coding gain is 3.8 dB (Type A), 8.8 dB (Type B), 9.7 dB (Types C,D). Effective power savings is reduced to about 2 dB for Type A, if carrier power threshold is not improved

  (It is worth noting that a coding scheme saving 6.3 dB can close the link with a 34m antenna instead of a 70m, with the same transmitted power and data rate)
- Given a ROM Cost Estimate of $318M to build 240 12m U/L-arraying antennas (80/Complex; each with 3.2 kW), coding can save millions with just a few dBs of improvement, with a modest investment (Mostly NRE, and additional S/C cost for decoder)
- Conclusion: uplink coding provides substantial benefits at the cost of a contained complexity increase on S/C (on-board decoder on single FPGA). Uplink coding is a very cost effective way to improve uplink performance